

OXIDATION RESISTANT AND BURN RESISTANT COPPER METAL MATRIX COMPOSITES

CROSS-REFERENCE TO RELATED APPLICATIONS

5 **[0001]** This application is a continuation-in-part/ of United States Patent Application No. 09/948,170 filed on 09/06/2001. The disclosure of the above application is incorporated herein by reference.

FIELD

10 **[0002]** The present invention relates generally to metal matrix composites, and more particularly to copper metal matrix composites that exhibit high strength, good burn resistance and good resistance to high temperature oxidation.

BACKGROUND

15 **[0003]** It is often difficult to form a metal alloy including a plurality of properties. For example, existing metal alloy and metal matrix materials may lack burn resistance in high pressure oxygen environments or oxidation resistance at elevated temperatures. The lack of burn resistance and oxidation resistance severely limits the effective use of such materials for oxygen-rich rocket engine
20 applications.

[0004] Previous attempts to overcome this problem include the use of aluminum oxide or alumina (i.e., Al_2O_3) particulate or alumina fiber reinforced aluminum matrix composites. Generally, these aluminum particles or fibers are formed during the alloying of a material. For example, alumina may be produced
25 during the oxidation of aluminum that may be an element as an alloying material. Various alloying procedures include using particles that are alloyed together.

During this alloying procedure, the various particles become oxidized to form the alumina. Aluminum-based alloys, however, are highly flammable in high pressure oxygen environments, making them unsuitable for oxygen-rich rocket engine applications.

5 **[0005]** Another approach included copper reinforced with refractory metal filaments. The copper matrix oxidizes, however, rapidly in oxygen-containing environments at elevated temperatures. The copper-rich oxides that formed may not be protective and may spall off severely during thermal cycling. Copper matrix composite may degrade rapidly because of its lack of high
10 temperature oxidation resistance. Finally, a graphite fiber reinforced copper composite has also been proposed. This material, however, is not suitable for oxygen rich rocket engine applications because it lacks both oxidation resistance and burn resistance.

[0006] Therefore, there exists a need for a material that exhibits high
15 strength, good burn resistance, and good resistance to high temperature oxidation, especially for use in conjunction with oxygen-rich rocket engine applications.

SUMMARY

[0007] The present invention may provide a new and improved metallic
20 alloy that is burn-resistant and oxidation-resistant.

[0008] According to various embodiments, the present invention may provide a new and improved copper-based metallic alloy that is burn-resistant and oxidation-resistant.

[0009] According to various embodiments, the present invention may provide a new and improved copper metal matrix composite that is burn-resistant and oxidation-resistant.

[0010] Further areas of applicability of the present invention will become apparent from the detailed description provided hereinafter. It should be understood that the detailed description and various examples, while indicating various embodiments of the invention, are intended for purposes of illustration only and are not intended to limit the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The present invention will become more fully understood from the detailed description and the accompanying drawings, wherein:

[0012] The Figure illustrates a graphical representation of mass gain of various copper-nickel-aluminum alloys as a function of aluminum content, in accordance with the general teachings of the present invention.

DETAILED DESCRIPTION OF VARIOUS EMBODIMENTS

[0013] The following description of various embodiments is merely exemplary in nature and is in no way intended to limit the invention, its application, or uses.

[0014] The present invention relates to metal matrix composites including copper metal matrix composite materials that exhibit high strength, good burn resistance and good resistance to high temperature oxidation. Briefly, a metal matrix composite is formed by reinforcing a metal alloy, the so-called matrix, with a reinforcing material that may be stronger and stiffer, these may

include ceramics. It will be understood, however, that the reinforcing material may be any appropriate material. The reinforcing material may include metal particles not in the allow or organic materials. Also ceramics may include both oxide and non-oxide ceramics. Generally, the reinforcing material may not melt or be degraded by the temperature and conditions of the infiltration or reinforcing procedure.

[0015] One method of synthesizing such a metal matrix composite is to inject the metal alloy (matrix) into a porous preform. Although any appropriate method may be used to form the metal matrix composite, the injection molding may be used for various reasons, such as production time, infiltration amount, and other various reasons. In addition, various specific methods may be used for the injection of the metal alloy into the ceramic perform, such as those described in U.S. Patent No. 6,360,809 entitled "Method and Apparatus for High Throughput Pressure Infiltration Casting" to James Cornie et al., incorporated herein by reference. In addition, the process for the metal infiltration may be that performed by Metal Matrix Cast Composites, Inc. of Waltham, Massachusetts. It will be understood, however, that such a process is merely exemplary and not intended to limit possible methods or processes that may be used to form the metal matrix composite. The alloys may be specifically created for any number of reasons depending upon the application into which the metal matrix composite may be placed. The metal or metal alloy is made molten and then pressure injected into the reinforcing material preform and once solidified forms the metal matrix composite.

[0016] Again, although various processes may be used, the metal alloy is generally rendered molten or melted before it is placed in the reinforcing

material pre-form. In this way, the metal alloy is in a substantially flowable state before it is provided into the reinforcing material pre-form. This allows for very little internal oxidation during the alloying and the infiltration process such that the alloy is formed with very little internal oxidation that may affect the properties of the alloy. Therefore, substantially all of the oxidized material that may be in the final cast product is generally predetermined and generally includes the reinforcement fibers, which may include alumina or other oxidized material, or any other appropriate materials.

[0017] In accordance with various embodiments of the present invention, a metal alloy may include about 2.5 to about 6 weight percent aluminum, about 3 to about 30 weight percent of nickel or zinc and the balance copper. According to various embodiments, the nickel or zinc percentages may be replaced with a combination of about 30 to about 50 weight percent of nickel and zinc. According to various embodiments, an alloy may include about 3.5 to about 4.5 percent aluminum, about 3 to about 30 weight percent zinc, 30 to about 50 weight percent nickel, and the balance copper. Additionally, small amounts of silicon, chromium, and titanium may also be present in the alloy. Generally, the silicon, chromium, and titanium, alone or in combination, comprise about 2 to about 7 weight percent of the metal alloy.

[0018] The copper alloy is preferably reinforced with about 15 to about 70 volume percent of reinforcing material. The reinforcing material may be in any selected form such as particulates, whiskers, or fibers. Nevertheless, as described herein, the reinforcing material may be used in any appropriate form. Various ceramic reinforcement materials may include alumina, silicon carbide,

and the like. Once the metal alloy is injected into the reinforcing material preform a metal matrix composite is formed.

[0019] The metal matrix composite comprises about 15 to about 70 volume percent ceramic particles with the remainder being the metal alloy.

5 Although the reinforcing material volume percent may be any appropriate amount, such as about 55 to about 70 volume percent. The copper metal alloy or matrix may then be reinforced with a particular particle or fiber. For example, ceramic particles, whiskers, fibers, or other appropriate reinforcing structure of the ceramic material may be used to reinforce or define a portion of the copper
10 metal alloy. For example, a selected volume of the matrix composite may include about 15% to about 70% of the ceramic material. Therefore, the alloy composite material may include about 30 to 85 percent of the matrix alloy and about 15 to about 70% of the ceramic particles. Although it will be understood that any appropriate ratio of the alloy matrix to the ceramic particles may be used
15 depending upon various concerns such as strength or the particular composition of the alloying and the particular selection of the ceramic fibers. For example, the ceramic particles may be selected from aluminum, silicon carbide and other appropriate materials.

[0020] The ceramic materials are preformed into a desired shape or
20 design. It will be understood that the ceramic materials need not be formed into an exterior shape. For example, the ceramic materials may be formed into an internal reinforcement structure around which the metal alloy is placed. Therefore, the ceramic materials may either define an exterior shape, an internal structure, or a combination of both. Nevertheless, it will be understood that the
25 ceramic materials may simply define an internal structure and the metal alloying

is formed around the internal structure to define the final shape of the product. The ceramic preform may be formed of particles, whiskers, fibers, other shapes of materials or combinations thereof, the selection may depend on the particular application into which the metal matrix composite will be placed. It will be understood that these materials are merely exemplary and any form of ceramic or similar materials may be used. Once the ceramic reinforcement is preformed, the liquid metal alloy that has been created is pressure injected into the preform. The metal alloy must melt at a sufficiently low temperature to allow easy injection into the matrix preform. Once the metal or metal alloy has been made into a molten material, it is injected under pressure created by an inert gas, such as nitrogen or argon, into the preform to ensure that the molten metal alloy infiltrates all of the spaces in the ceramic preform. It will be understood that the alloying may be positioned around the preform in any appropriate manner, and the injection infiltration process is merely exemplary. Nevertheless, an exemplary injection infiltration process as described in U.S. Patent No. 6,360,809 issued March 26, 2002 entitled "Method and Apparatus for High Throughput Pressure Infiltration Casting", the disclosure of which is incorporated herein by reference. Nevertheless, other infiltration methods may be used, such as gravity or centrifugal.

[0021] The metal alloy may also be formed at any appropriate time. For example, the metal alloy may be alloyed prior to making the alloy flowable for the infiltration process.

[0022] Regardless, according to various embodiments, the alloying is generally closely surrounding and completely infiltrating all portions of the reinforcement preform. Therefore, the forced infiltration processes may increase

the ability to fill all voids of the preform with the molten alloy. In addition, the alloy may be tightly bonded to the ceramic or reinforcement materials. Therefore, the forced infiltration processes may also assist in assuring a large contact surface area and pressure to ensure the interconnection or adhesion of the alloy metal material to the reinforcement material.

[0023] The reinforcing material may include any appropriate type of material. In addition, the reinforcing material may include various shapes and sizes of materials. For example, two general types of reinforcing materials or particles may be used, such as a continuous or a long fiber, a discontinuous or particulate, or a cut fiber. Generally, a continuous fiber is a fiber that includes at least one dimension that is substantially equal to a dimension of the material or the formed component. Therefore, a continuous fiber when used as preform reinforcement material will generally include at least one dimension that is equal to one dimension of the preform size. Generally, however, the fibers include a diameter that are between about 5 and about 30 micrometers. Therefore, the length over diameter ratio may be substantially large. A cut fiber reinforcement material may include a fiber that includes a length or a diameter ratio that is still fairly large, yet the length is still not the length of a preform shape. A particulate material may generally include a particle size that includes an average diameter of a selected diameter such as about 5 to about 100 micrometers.

[0024] The reinforcing material or particles is generally positioned in the preform or to form the preform in a selected shape. The preform is then positioned in an appropriate mold, such as a graphite mold, to allow for the infiltration of the selected alloy around the reinforcing material. As described above, the pressure infiltration system may be used to infiltrate the alloy around

the reinforcing material. Nevertheless, the reinforcing material, also as described above, generally includes about 15 to 70 percent of the volume of the final construct. Nevertheless, the reinforcing material may be at least 55 volume percent of the final product depending upon the particulars of the final construct.

- 5 Therefore, the reinforcing material may be a majority of the final construct while the metal alloy is actually a minority of the final construct.

[0025] Also, it may be desirable to form the preform in a selected manner. For example, the continuous fiber reinforcing material may include a strength that is greater in a longitudinal direction than in a transverse direction.

- 10 Therefore, the reinforcing material may be positioned and placed in a preform in such a manner such that the final product or construct will include the fibers laying longitudinal along a high stress direction such that high stress direction will have the greatest strength. While the continuous fibers may have a substantially high strength in a longitudinal direction, the particles or cut fibers may include a
- 15 substantially different and substantially isotropic strength. Therefore, having the particles or the cut fibers may be useful for a component that includes a substantially isotropic applied stress.

[0026] In addition, the various reinforcing materials may be used with differing alloying compositions. For example, a high strength alloy such as a

20 copper based alloy including four weight percent aluminum, 30 weight percent zinc, about one weight percent titanium, and the balance copper may be used for particulate reinforcement material. An additional exemplary alloy may include a 13 weight percent nickel, three weight percent aluminum, about one weight percent chromium, about two weight percent titanium, and the balance copper.

- 25 When a particulate reinforcement material is used, a substantially strong alloy

may be used to infiltrate the preform. The strong alloy may include a substantially high melting point without deleteriously effecting the properties of the reinforcing material.

[0027] When the reinforcing material is the substantially continuous
5 fiber material, the metal alloy may be a different or lower melting point alloy. For example, an alloy including about four weight percent aluminum, about 30 weight percent zinc, and the balance copper may be used for infiltrating a continuous fiber preform. Without being bound by the theory, the alloy including the copper, aluminum, and zinc may include a lower melting point and a lower ductility. The
10 lower melting point may allow the alloy to be infiltrated into the preform without affecting the fibers, such as sintering the various fibers together. In this way, the fibers are not degraded by sintering the fibers together and each remains substantially alone in the final construct. In addition, the lower ductility may allow the continuous fibers to provide strength reinforcements to the construct
15 without being substantially adhered to a non-ductile metal alloy.

[0028] Regardless of the reinforcing material, such as the composition, shape, size, and other characteristics, generally the component or construct is substantially structural component. That is, the preform is substantially a structural component and the infiltrated alloy completes the structural component.
20 That is, the metal matrix composite is not a coating or layer on a separate material, but generally defines a structural component. Therefore, the characteristics are substantially uniform throughout the structural component such that the high burn and oxidation resistance is coupled with the high strength through the entire component. Therefore, the components may be used in high
25 oxygen pressure and high oxidation environments without degrading even if a

small portion of the component is damaged because the component includes the substantially continuous or uniform properties throughout,

[0029] Test data for burn resistance of the metal alloys of the present invention is shown in Table I, below. The data represented in the table includes weight percents, where given, and the balance being copper. It is understood by one skilled in the art that alloys generally include unremovable or uncounted impurities. Therefore, the alloys may include other elements that are not listed and which may not affect the properties of the alloy due to the existence of unaccounted and unremovable impurities. The threshold pressures, or threshold burn resistance pressures, of test samples comprising 0.13-inch diameter rods ignited at the bottom were recorded. Threshold pressure is defined as the minimum pressure of substantially pure oxygen in pounds per square inch (psi) required to support complete combustion of the test sample. In greater detail the tests are performed by igniting a bottom portion of the rod and observing whether the test sample self extinguishes. The threshold pressure is also the minimum pressure of pure oxygen at which the test sample will self extinguish.

TABLE I

Material/Alloy (weight percent)	Threshold Pressure (psi)
Aluminum (99.9)	25
Copper - Aluminum (12)	200
Copper - Aluminum (9)	300
Copper - Aluminum (7)	1,000
Copper - Aluminum (5)	>10,000
Copper - Nickel (20) - Aluminum (5)	>10,000
Copper - Nickel (4.6) - Aluminum (4) - Chromium (1)	>10,000
Copper - Nickel (4.6) - Aluminum (4) - Silicon (1)	>10,000
Copper - Nickel (4.6) - Aluminum (4) - Silicon (2)	>10,000
Copper - Nickel (4.6) - Zinc (30) -	>10,000

Aluminum (4)	
Copper - Nickel (4.6) - Aluminum (4) - Chromium (1) - Titanium (0.5)/Alumina particulate	>5,000

[0030] The data demonstrates that conventional aluminum or copper-aluminum alloys containing greater than 7 weight percent aluminum have threshold pressures below 1500 psi. In contrast, a number of copper-aluminum, copper-nickel-aluminum, copper-nickel-zinc-aluminum alloys, in accordance with general teachings of the present invention exhibit no, or only minimal, burning in 5,000 psi or higher oxygen pressures. An alloy with a ceramic reinforcement of alumina was also tested. Alumina particulate reinforced copper-nickel-aluminum-chromium-titanium alloy also demonstrated burn resistance at 5,000 psi or higher threshold pressure.

[0031] In applications requiring high oxygen pressures, it is desirable to have a material that has a burn resistance at these high oxygen pressures. Burning of a material generally includes a strong and continuous oxidation reaction. Although oxidation may include a generally slow reaction where a portion of a material may oxidized and then loose structural cohesion, generally on a surface of the material, burning may be described as a more involved reaction. If the material does not have a burn resistance at high oxygen pressures, then the material will potentially burn without extinguishing thereby rendering the system into which the material has been placed useless. Therefore, the applications described herein require materials to have a burn resistance of at least a threshold pressure of 5,000 psi.

[0032] Test data for high temperature oxidation resistance of the matrix alloys of the present invention is presented in Table II, below. The data included

in Table II also includes general weight percents, where given, with the balance being the copper or unlisted material. Also, as described above, oxidation is generally a degradation of the material over a period of time. Generally, the oxidation occurs on the surface of the material, thereby reducing the structural integrity of the surface of the material allowing the surface oxidized portions to flake off. Several test metal alloys were formed and their respective mass changes when oxidized in air at 760°C (1400°F) and 871°C (1600°F) were recorded. The oxidation rates of various alloys were evaluated by fixed-time mass-gain measurements.

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Table II

Composition (weight percent)	Mass gain (mg/cm ²) 20 hours @ 760°C	Mass gain (mg/cm ²) 40 hours @ 871°C
OFCH copper	14.1	44.2
copper - nickel (20)	6.1	37.8
copper - nickel (3) - silicon (1) - chromium (1)	5.7	26.1
copper - aluminum (3) - chromium (1)	0.57	1.08
copper - aluminum (5)	0.41	0.50
copper - nickel (20) - aluminum (5)	0.14	0.47
copper - nickel (4.6) - aluminum (4)	0.24	0.26
copper - nickel (4.6) - aluminum (4) - silicon (1)	0.02	0.09
copper - nickel (13) - aluminum (3) - chromium (1)	0.13	0.12
copper - nickel (4.6) - aluminum (4) - chromium (1)	0.22	0.41
copper - nickel (4.6) - aluminum (3) - silicon (2)	0.22	0.72
copper - nickel (4.5) - aluminum (4) - manganese (12)	0.09	0.18
copper - nickel (4.5) - aluminum (4)	0.08	0.33

copper - nickel (4.5) - aluminum (4) - chromium (1)	0.31	0.33
copper - zinc (30) - aluminum (4)	0.02	0.31
copper - nickel (4.5) - aluminum (4) - zinc (15)	0.09	0.09

[0033] As shown in Table II, the oxygen-free high-conductivity (OFHC) copper has a high oxidation rate in air. The scale that formed is not protective and spalled severely during cooling to room temperature. The copper-Ni(20) or Copper-Ni(3)-Si(1)-Cr(1) alloys, where the numbers in parenthesis indicate weight percent of that element in the alloy, that contained no aluminum also showed high mass changes indicating poor oxidation resistance. With the addition of 3 to 5 weight percent aluminum to the copper or copper-nickel alloys, the mass changes of the alloys in air at elevated temperatures are reduced by more than 10-fold. The alloys formed a thin, adherent alumina scale that acted as a barrier for outward copper ion diffusion and inward oxygen migration.

[0034] It was found that the addition of aluminum caused the formation of a protective scale on the alloy reducing the oxidation mass gain. Thermogravimetric analysis (TGA) was performed on several alloys comprising copper, nickel (5), and aluminum (various weight percentages) to assess the protective scales formed on alloys with differing aluminum content. The data is presented in the Figure. The copper-nickel-aluminum alloys that contained less than 2 weight percent aluminum showed high mass gains. A marked reduction in mass change occurred for the copper-nickel-aluminum alloys where aluminum comprised at least 2.5 weight percent of the alloy. In copper-nickel-aluminum

alloys containing 3 to 5 weight percent aluminum, protective alumina scales were formed and very low mass gains were observed at all test temperatures.

[0035] Several parts of vehicle engines now in production use heavy cast and machine metal parts. The engines use turbines in turbo pumps which require materials that can withstand burn and oxidation pressures. Turbomachinery components of a rocket engine for a reusable launch vehicle (RLV), including turbine housings, are the heaviest parts of the engine. These components are currently made of nickel or cobalt-based alloys which have a density of approximately 0.3 lb./in. (8,300 kg/m). When using metal matrix composites of equivalent strength the density of material is reduced to 0.22 lb./in. (6,090 kg/m). Replacement of these nickel or cobalt based alloy components with metal matrix composites parts will reduce the engine weights by 10 to 30%. The weight reduction can be transformed to lower propellant consumption and higher payload.

[0036] The materials of the present invention may be useful in replacing many heavier cast metal pieces with the metal matrix composite materials being produced in accordance with the present invention. The materials made with the metal matrix composites are much lighter than those produced with the standard cast methods. A weight and cost model has been used to correlate the weight reduction to the cost savings for a reusable launch vehicle (RLV). Every pound (lb.) of engine weight reduction corresponds to a reduction of about 3.03 lbs. of vehicle dry weight. Using the metal matrix composites of the present invention, a turbo pump designed for the engines may reduce engine weight by about 200 lbs. The model states that the weight reductions equal to 200 lbs. per engine multiplied by seven engines per RLV

multiplied by 3.03, for a total weight reduction of 4,242 lbs. The development cost savings in millions of dollars is equal to $(273,333 \text{ lb. vehicle dry weight})^{0.61} - (273,333 \text{ lb. vehicle dry weight} - 4,242 \text{ lb.})^{0.61}$ which equals 2072.0-2052.3 totaling 19.7 which is nearly a \$20 million savings.

5 **[0037]** The metal matrix composites of the present invention, as briefly described above, are formed by molten alloy infiltration into the ceramic preforms. The ceramic reinforcements are preformed near the net shape of the selected design to be produced. The metal alloys are made flowable and may be pressure injected into the preformed ceramic preform. This reduces the
10 production costs of the final component since less finishing of the part is required. This is an additional cost savings over the simple weight reduction of the RLV.

[0038] The materials in the present invention not only have the characteristics of having increased burn resistance and decreased oxidation, but also are useful for an infiltration preform method. Metal alloys including copper
15 and other metal elements have a low enough melting point to be used in the infiltration process to produce the preformed metal matrix composites. Generally, the melting point of the metal alloy must be low enough to use the infiltration process with affordable steel equipment. According to the present invention zinc is a metal alloying element that provides both the strength requirement, and the
20 low melting point. Metals such as nickel provide strength, while increasing the melting point of the alloy to which they are added. The metal alloys themselves, however, do not easily adhere to the matrix composites.

[0039] The minor elements, according to various embodiments of the present invention, may help ensure a strong adhesion between the main metal
25 alloy and the ceramic reinforcing particles. The minor elements, including silicon,

selected oxidation resistance, and a selected tensile strength. Generally, for the examples, it was selected that the burn resistance would be the ability of a test rod to extinguish a flame while in at least about 5,000 psi oxygen. The oxidation resistance is a material that is able to achieve a mass gain of less than about 1.0 mg/cm² and possible less than about 0.6 mg/cm², over a period of 20 hours at 760 °C in ambient atmosphere or oxygen. In addition, the material was selected to include a tensile strength of at least about 70 ksi and possibly at least about 85 ksi at ambient temperature. The tensile strength is measured by a standard (ASTM) tensile test.

10 **[0044]** Each of the following examples were prepared by first alloying the metal alloy by melting the various proportions of the components in a generally known manner. One skilled in the art will understand that alloying materials generally occurs by melting selected proportions in a non-oxidizing atmosphere such that the components will melt and mix together in a selected
15 manner. The various alloys are then, in a melted or flowable state, pressure injected into a selected preform as is also generally known in the art. The process performed by Metal Matrix Cast Composites, Inc. of Waltham, Massachusetts was used in these examples. After the preform has been pressure injected with the selected alloy and solidified by cooling, the final
20 product made may then be heat treated and cured according to generally known techniques. Generally heat treating simply allows the final product to attain the selected mechanical properties of the alloy in the preform without being degraded by an exterior environment.

25 **[0045]** In Table 1, each of the alloy compositions may include an elemental sign preceded by a number. The number preceding the elemental sign

is a weight percent of that element in the metal alloy. Generally, copper is the balance alloy and does not include a number preceding the elemental sign thereby indicating that is the balance element.

[0046] In addition, each of the final products, according to the examples in Table 1, includes a volume majority of the reinforcement material. The examples in Table 1 include a particulate reinforcement material, the particulate is aluminum oxide or alumina (Al_2O_3). The particles of alumina may be any appropriate size, but may be about 1 micrometer to about 30 micrometers. In these examples, the particles are about 1 to about 20 micrometers on average. Therefore, the metal alloy portion of the final composite material is actually a volume minority of the final product. According to the particulate examples, the aluminum oxide is about sixty-one volume percent of the final product. Although the metal alloy may be more dense and include a higher weight percentage of the final product, the volume percent of the final product includes more of the aluminum oxide than of the metal alloy.

[0047] Tests were performed in each of the exemplary metal alloy composites shown in Table 1. The various tests, as described above, were to test the burn resistance, oxidation resistance, and tensile strength of the metal alloy composite. The results of Table 1 illustrate at least one criteria not met by the alloy composite. The table lists the various metal alloys and the down side of each of the alloy compositions.

Table 1

ALLOY COMPOSITION	CRITERIA NOT MET
Cu-6Ni-4Al-1Cr-0.5Ti	Melting temperature too high and ductility too low
Cu-3Ni-4Al-1Cr-0.5Ti	Tensile strength too low
Cu-4.5Ni-6Al-1Cr-0.5Ti	Inadequate resistance to promoted combustion in high pressure oxygen

Cu-4.5Ni-2Al-1Cr-0.5Ti	Inadequate oxidation resistance in elevated temperature air or oxygen
Cu-4.5Ni-4Al-2Cr-0.5Ti	Inadequate burn resistance in high pressure oxygen and melting temperature too high
Cu-4.5Ni-4Al-0.2Cr-0.5Ti	Tensile strength too low
Cu-4.5Ni-4Al-1Cr-1Ti	Reacts with Al_2O_{3p} , tensile strength too low and inadequate burn resistance in high pressure oxygen
Cu-4.5Ni-4Al-1Cr-0.2Ti	Insufficient to provide liquid alloy wetting of Al_2O_{3p} resulting in porous alloy composite and low tensile strength

[0048] Although each of the compositions in the table included a particular fault, a further example includes Cu-4.5Ni-4Al-1Cr-0.5Ti in a final product that includes a 61 volume percent of aluminum oxide. This example included a burn resistance threshold of greater than about 5,000 psi oxygen and an oxidation resistance of less than about 0.25 mg/cm² mass gain in 20 hours at 760 °C. In addition, this exemplary product includes a tensile strength of about 78 ksi and includes a ductility and melting point that was appropriate that did not degrade the reinforcement material.

[0049] As described above, each of the products described in Table 1 include a volume percent of about 61 percent aluminum oxide. Nevertheless, the exemplary copper alloy including about 4.5 weight percent nickel, about 4 weight percent aluminum, about 1 weight percent chromium, and about 0.5 weight percent titanium, with the balance being copper, in a composite of appropriately 61 volume percent aluminum oxide particles achieved to selected results. As described in Table 1, each of the other alloy compositions include an elemental range that does not achieve the selected characteristics. For example, and not intending to be limited by the theory, it is believed that higher nickel weight percents generally increase the melt point of the alloy to a temperature that is too

high to allow for ease of flowability and wetting of the aluminum oxide preform. In addition, the high metal point of the alloy may disturb the aluminum oxide preform during the infiltration process. A large amount of the aluminum and chromium may be reduced the burn resistance, particularly in the high oxygen environment.

5 **EXAMPLES FOR REINFORCEMENT FIBERS**

[0050] The metal alloys tested in the following examples were formed in substantially a similar manner as those subscribed above. Briefly, various amounts of the elemental components were melted together to form the metal alloy which were then injected into the preform. The reinforcement fibers, however, are first laid or woven in the selected manner. As discussed above, the fibers may include a tensile strength which is much greater along the longitudinal length than the transverse thereto. Therefore, it may be selected to have all the fibers lay in a particular manner to achieve a strength in a selected direction or substantially randomly or selectively orient the fibers to include a more isotropic force resistance or distribution. The fiber used is Nextel 610 fiber produced by 3M Corporation.

[0051] Table 2 includes various alloy and elemental ranges indicated as discussed above. Table 2 includes comparative examples of alloys and fiber composites that may not achieve the selected characteristic ranges. In addition, each of the final products include the volume percent of about 61 percent of the Nextel 610 fiber. Therefore, although the metal alloy may be a larger weight percent of the final product, the fiber reinforcement material is a greater volume percent. The selected results for the examples are substantially similar to those for the particulate examples and Table 2 includes the various alloy and elemental

compositional ranges and the various reasons why the selected example did not achieve the selected results.

Table 2

ALLOY COMPOSITION	CRITERIA NOT MET
Cu-6Al-30Zn	Inadequate resistance to promoted combustion in high pressure oxygen
Cu-2Al-30Zn	Inadequate oxidation resistance in elevated temperature air or oxygen
Cu-4Al-35Zn	Strength too low and reduced burn resistance in high pressure oxygen
Cu-4Al-25Zn	Melting temperature too high-damages Nextel fiber integrity and lowers MMC strength.

5 **[0052]** Although the above described examples included various results that do not achieve selected parameters an exemplary composition including Cu-4Al-30Zn in a final product including approximately 61 volume percent of the Nextel 610 fiber did achieve selected parameters. This exemplary product achieved a burn resistance threshold of about 5,000 psi oxygen and an oxidation
10 resistance of less than about 0.25 mg/cm² mass gain in 20 hours at 760 °C. In addition, the tensile strength of the product, along the fiber axis, was about 180 ksi.

[0053] As discussed above, and not intended to be limited by the theory, various elemental ranges may not achieve selected results. For example
15 a low amount of zinc may increase the melting temperature of the alloy to one that may degrade the fibers. At too high a temperature the fibers may sinter together during the infiltration process. Sintering the fibers may remove the high longitudinal tensile strength inherent in the fiber material. Also a combination of a weight percent of aluminum with the other elements may not achieve a selected
20 burn or oxidation resistance.

[0054] Therefore, the above examples illustrate how various elemental ranges in selected alloys do not allow for the achievement of selected parameters. Rather, selected ranges achieve various characteristics that may be selected for various applications. Particularly, in a structural component selected strength ranges may be selected and achieved. Nevertheless, the various strength achievements may be selected to be met while achieving various oxidation and burn resistance parameters. In a high oxidation and high temperature environment, such as in a rocket engine, all of the various physical characteristics may coincide to ensure proper operation of the component.

[0055] The description of the invention is merely exemplary in nature and, thus, variations that do not depart from the gist of the invention are intended to be within the scope of the invention. Such variations are not to be regarded as a departure from the spirit and scope of the invention.